NuMI-B-796

Locating the neutrino beam elements

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A. Para, Fermilab

Abstract

A simple system for precise determination of the horns position during the commissioning, as well as during the data taking phase of the experiment is described.

1 Introduction

Direction and NuMI neutrino beam is determined by the alignment of the primary proton beam, target and focusing horns. These elements will be aligned to point to Soudan on a with a combination of GPS and optical survey. The expected accuracy of positioning of the beam devices on the line pointing to Soudan is of the order of 0.5 mm. This accuracy should ensure that the resulting neutrino beam points to the far detector with the accuracy of the order of 10 microradians, thus ensuring that the systematic errors on the neutrino flux prediction are negligible.

2 What is the Problem, then?

Beam position monitors, neutrino target, and horns will be perfectly aligned during the installation. Some additional means of verification of the horns position are nevertheless desirable for several reasons:

- given the importance of the knowledge of the neutrino beam for the oscillation experiment it is important to be able to demonstrate the correctness of the alignment using the beam-related data
- it is possible that the beam element may move during the run of the experiment. It can be a result of thermal expansion of the target cave, settling of the floor of the cavern or some other, unknown at this time, reason. Such a displacement would probably produce a detectable change of the response of the beam monitoring devices.
- the beam monitoring system is designed to certify that the beam conditions remain unchanged during the experiment. It provides not enough information, though, to understand what is the cause of the putative change of the beam condition. An independent system of verification of the position of the individual beam devices would be of great value as a diagnostic tool.
- it is expected that during the lifetime of the experiment some of the beam devices may fail and will have to be replaced. Highly radioactive environment of the target area will make a detailed survey of the replaced devices more difficult. An in-situ positioning system would allow a cross-check of the alignment of the replaced elements.

3 Horn Positioning System

The primary proton beam position will be known with the accuracy of several hundred microns from the multiwire chambers and the Beam Position Monitors (BPM's). This beam can be used, with full or reduced intensity, to locate various beam devices. The devices which are the most critical for the neutrino beam are the horns, especially the first one, as they define the direction and the composition of the secondary beam. Alignment of the horn protection baffle is important too, as the proton beam scraping the interior of the baffle will produce unwanted component of the neutrino beam. Precise alignment of the neutrino target is not critical as the direction of produced pion flux is determined primarily by the direction of the proton beam.

The baffle and the horn have a common characteristic: a central opening of a diameter ranging from 1 cm to several cm. As a design of the baffle is still under discussion, we will concentrate on the horns here. The presented scheme will function equally well for the baffle with the opening much larger than the size of the primary proton beam.

The concept of the positioning system consists of a pair of wires strung across the downstream end of the horns and a standard beam loss monitor (BLM) positioned downstream of the horn. Scan of the opening of the horn with the proton beam, whose position is precisely known from the BPM's, should produce an increase of a signal in the BLM when the proton beam strikes the wire, hence providing a precise measurement of the wire coordinate with respect to the beam coordinate system. This scan would have to be performed with the neutrino production target positioned out of the beam.

4 Will it work?

Standard beam loss monitors are ion chambers with central wire at a bias of 500-1500 V with respect to the outer case. Their absolute calibration is performed with the help of radioactive sources, hence it is expressed in terms of current vs Rads/sec. Typical sensitivity values are of the order of 100 pC/Rad. The sensitivity of these monitors to a signal induced by a proton beam striking a wire is quite cumbersome to derive, however.

There is a significant amount of experience with BLM's used to monitor various beam lines at Fermilab. We expect to use them to monitor beam losses along the primary proton beam line, where the required sensitivity corresponds to the $10^8 - 10^9$ interacting protons.

Assuming, for the sake of argument, that the position scan would be performed with a low intensity proton beam, say 10^{12} protons per pulse, we conclude that a wire representing 1% or more of the interaction length should produce a signal easily detectable with the BLM.

5 Expected Signal to Noise Ratio

Neutrino beam devices, located in the target cave, are in air, hence the expected signal of the proton beam striking a wire will we observed on a background induced by the interactions of the proton beam with air molecules.

The exact balance of these two sources of particles will depend on the details of the material distribution inside the cave as well as on the location of the BLM's. For example, material of the horn will intercept some of the particles produced upstream of it, thus reducing the background.

As a guess we take that the background will be equivalent to that produced by 10 m of air.

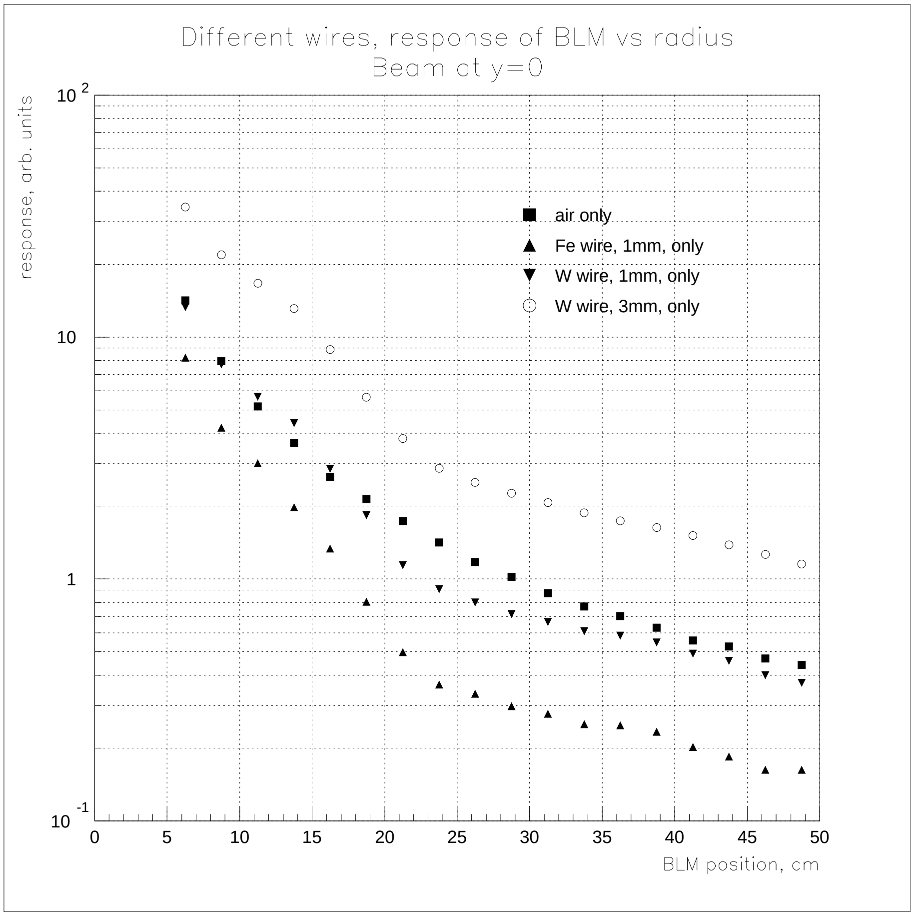

Figure 1: Signal induced in beam loss monitors located at different distances from the beam axis by proton beam interacting with air and with iron and tungsten wires. Vertical scale is in arbitrary units.

Fig. 1 shows a relative energy deposition in detectors located at different radial positions by particles produced by interactions of a proton beam with a gaussian profile, $\sigma = 1\ mm$, with air molecules and tungsten and iron wires. Detector is located 1 m downstream of the wire position. Wires are assumed to have a cross section of 1 mm (in a direction perpendicular to the beam) $\times 1(3)$ mm (along the beam direction).

Particles produced by $120\,GeV$ protons are well collimated, hence, given the difference in the acceptance for an extended source (i.e. air) and a point source (i.e. wire), the optimal signal-to-noise ratio is achieved at small radii $R < 15\ cm$. In this region a further improvement of this ratio will come from the shadowing by the body of the horn.

In a simple case of a single wire in air one can achieve a signal to noise ratio of the order of $1:2$ with $1\,mm \times 1\,mm$ square iron wire. This ratio is a product of the relative amount of the interaction length traversed and the corresponding geometrical acceptances. Replacing iron wire with a tungsten one improves the signal by a factor of two. Further improvement can be achieved by making the wire thicker along the beam direction.

The above exercise demonstrates that the signal from the beam striking the wire should be easily detectable above the background of particles produced in the air. It should be noted that the scan requires only a few proton pulses, hence it will be performed in a very short time interval. This reduces potential problems with the stability of the response of the beam loss monitors.

6 How accurately the wire can be located?

Fig. 2 shows a response of the beam loss monitors located $15\,cm$ away from the beam axis as a function of the beam position, as measured by the beam position monitors, for a case of $3\,mm$ thick (along the beam direction) tungsten wire.

The shape of the response curve is a result of a convolution of the wire geometry ($1\,mm$ in a direction perpendicular to the beam) and the proton beam spot ($\sigma = 1.1\,mm$ in a direction perpendicular to the wire and $\sigma = 0.7\,mm$ in a direction along the wire). A precision of the order of $200\,microns$ can be easily achieved with a standard focusing of the proton beam.

Proton beam can be easily focused to a much smaller spot, down to a $\sigma < 0.2\,mm$ [1]. Smaller beam size would offer further improvement of the position measurement accuracy, which is probably of no particular value but it may be necessary to reduce a potential background from the tails of the beam striking other materials upstream of the wire, such as the baffle or the neck of the horn.

Fig. 3 shows a response of the beam loss monitors located $50\,cm$ away from the beam axis as a function of the beam position, as measured by the beam position monitors, for a case of $3\,mm$ thick (along the beam direction) tungsten wire. It shows that the determination of the wire position is very insensitive to the location of the beam loss monitors, although their response may be quite different.

7 Effect of the walls of the target cave

Results shown in the previous section demonstrate a feasibility of the position measurement in the idealized case of a single wire floating in air. In reality there will be

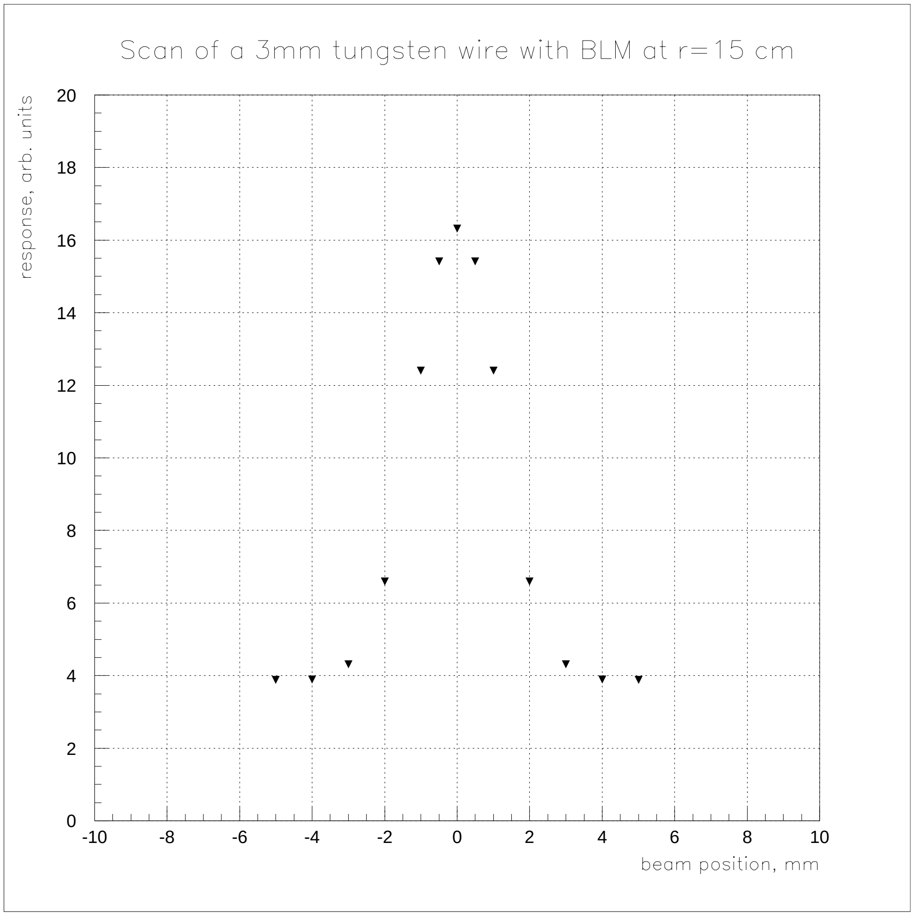

Figure 2: Response of the beam loss monitors located 15 cm away from the beam axis during the scan across the tungsten wire. Wire is 1 mm thick across the beam and 3 mm thick along the beam.

other sources of backgrounds, and the dominant is likely to be particles production in the walls of the target cave.

Fig. 4 shows the response of the beam loss monitors as a function of their position in two cases: air only and the square iron cavity filled with air, with the cavity walls positioned at $x, y = \pm 40\,cm$. As expected, there is an increased background in the detectors positioned near the walls of the cavity. This increase is predominantly due do electromagnetic showers produced by secondaries interacting with the walls.

Although this increase, even in the vicinity of the walls, does not endanger the sensitivity of the scanning, it is probably better to position the beam loss monitors at a smaller distance from the beam axis to eliminate the problem.

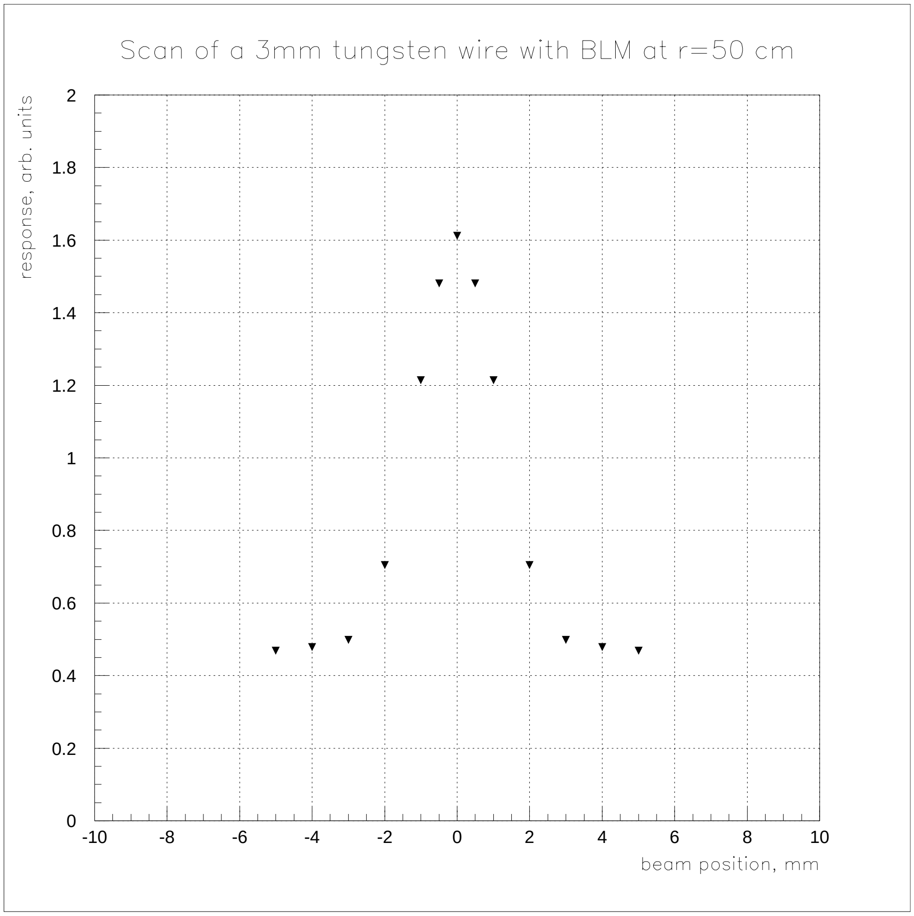

Figure 3: Response of the beam loss monitors located 15 cm away from the beam axis during the scan across the tungsten wire. Wire is 1 mm thick across the beam and 3 mm thick along the beam.

8 Will the BLM's survive in the target cave?

Scan of the wire with the help of BLM's can validate the initial position of the horns. If the wire/BLM's setup is to be useful in verifying the alignment of the beam elements during the data taking, in diagnosing potential mishaps with the beam line or in positioning the replacement horns it is necessary that they operate correctly in a highly radioactive environment.

There are two potential issues:

- radiation-induced background contributing to the signal of the BLM's
- radiation hardness of the BLM's themselves

Radiation-induced background can be reduced in two ways:

- by gating the response of the BLM's with the beam gate. It will provide a factor of 10^5 of the background rejection.

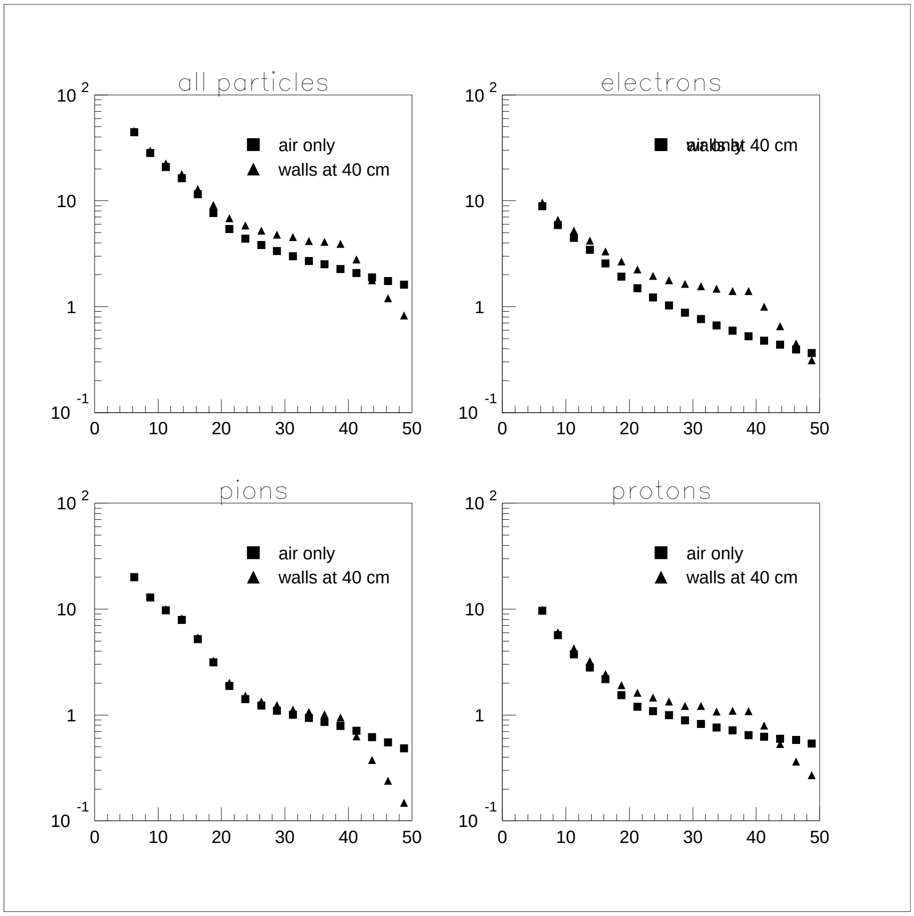

Figure 4: Response of the beam loss monitors as a function of their position in the 'air only' case and inside the iron cavity filled with air. Top left figure shows the total response. The remaining figures show the electron, pion and proton component of the response. It is assumed that the response is proportional to the energy loss of these particles.

- by shielding the BLM's with lead. As the 'signal' part of the response is created by high energy hadrons, such a lead shield will not degrade the response of the monitors, while reducing the soft radiation background.

The question of survivability of the BLM's is more difficult. It is very likely that the detectors themselves are quite robust, but the connectors and/or cables may be damaged by a long exposure to the radiation field of the target cave.

The simple solution ensuring the reliable operation of the system could consist of making an opening in the roof of the shielding of the target cave to position the BLM's near the beam axis for the period of a scan. This opening would be normally closed with an appropriate plug.

The accuracy of the scanning procedure does not depend on the precise positioning of the BLM',s, hence some relatively simple system can be probably constructed.

9 What needs to be done

If we decide that a verification of the positions of the beam devices is indeed a very important goal to achieve, the following steps would have to be taken:

- develop a scheme for precision mounting of the crossed wires on the downstream end of the horn(s).
- construct a shaft in the ceiling of the target cave for lowering of the BLM'
- design a mechanism for positioning of the BLM's downstream of the horn positions
- install BLM's, readout electronics, interface to ACNET, etc..

The scanning operation requires proton beam to be transported to the desired positions. For position determination of the horns it implies that the target must be in its 'out-of-beam' position. Flexibility of the target assembly and, in particular, a possibility of a controlled movement of a target with a minimal loss of time will be of significant importance.

References

[1] Peter Lucas says so